

ORIGINAL ARTICLE

2008 Outbreak of Salmonella Saintpaul Infections Associated with Raw Produce

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ABSTRACT

BACKGROUND

Raw produce is an increasingly recognized vehicle for salmonellosis. We investigated a nationwide outbreak that occurred in the United States in 2008.

METHODS

We defined a case as diarrhea in a person with laboratory-confirmed infection with the outbreak strain of *Salmonella enterica* serotype Saintpaul. Epidemiologic, traceback, and environmental studies were conducted.

RESULTS

Among the 1500 case subjects, 21% were hospitalized, and 2 died. In three case-control studies of cases not linked to restaurant clusters, illness was significantly associated with eating raw tomatoes (matched odds ratio, 5.6; 95% confidence interval [CI], 1.6 to 30.3); eating at a Mexican-style restaurant (matched odds ratio, 4.6; 95% CI, 2.1 to ∞) and eating pico de gallo salsa (matched odds ratio, 4.0; 95% CI, 1.5 to 17.8), corn tortillas (matched odds ratio, 2.3; 95% CI, 1.2 to 5.0), or salsa (matched odds ratio, 2.1; 95% CI, 1.1 to 3.9); and having a raw jalapeño pepper in the household (matched odds ratio, 2.9; 95% CI, 1.2 to 7.6). In nine analyses of clusters associated with restaurants or events, jalapeño peppers were implicated in all three clusters with implicated ingredients, and jalapeño or serrano peppers were an ingredient in an implicated item in the other three clusters. Raw tomatoes were an ingredient in an implicated item in three clusters. The outbreak strain was identified in jalapeño peppers collected in Texas and in agricultural water and serrano peppers on a Mexican farm. Tomato tracebacks did not converge on a source.

CONCLUSIONS

Although an epidemiologic association with raw tomatoes was identified early in this investigation, subsequent epidemiologic and microbiologic evidence implicated jalapeño and serrano peppers. This outbreak highlights the importance of preventing raw-produce contamination.

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SALMONELLA IS A LEADING BACTERIAL cause of gastroenteritis in the United States, and the incidence has changed little in the past decade.¹ Produce that is eaten raw is an increasingly recognized vehicle for transmission of pathogens, including salmonella species.^{2,3}

On May 22, 2008, the New Mexico Department of Health notified the Centers for Disease Control and Prevention (CDC) about 19 cases of salmonella infection in May. All seven isolates with completed serotyping were *Salmonella enterica* serotype Saintpaul.⁴ Four of the tested isolates had indistinguishable patterns on pulsed-field gel electrophoresis (PFGE). On May 23, the CDC's staff at PulseNet (a national molecular-subtyping network) identified three additional isolates with the same PFGE pattern from Colorado and Texas. In 2007, only 40 human Saintpaul isolates with this pattern were submitted to PulseNet. This report describes the nationwide investigation of what became a large foodborne outbreak in the United States.

METHODS

OUTBREAK IDENTIFICATION AND CASE FINDING

Clinical laboratories send salmonella strains from ill persons to state public health laboratories for serotyping and PFGE subtyping with the use of standardized methods.^{5,6} State public health laboratories routinely submit PFGE patterns to PulseNet. We defined a case as laboratory-confirmed infection with the Saintpaul serotype of *S. enterica* with PFGE XbaI pattern JN6X01.0048 (the outbreak strain) from April 1, 2008, through September 4, 2008. For all studies, we defined diarrhea as at least three loose stools in a 24-hour period.

EPIDEMIOLOGIC STUDIES OF CASES NOT LINKED TO RESTAURANT CLUSTERS

We initially interviewed case subjects in Texas and New Mexico to generate hypotheses about the source of infections. Three case-control studies were conducted to assess exposures among case subjects that were not linked to restaurants or other common events. Exposures were ascertained by means of interviews, which focused on the week preceding the illness (for case subjects) or the week preceding the interview (for control subjects). All study participants provided oral consent.

Study 1

In May 2008, the departments of health in New Mexico and Texas, the Navajo Nation, the Indian Health Service, and the CDC conducted a case-control study. To generate hypotheses, case subjects were interviewed with the use of a detailed questionnaire about consumption of numerous food items, including red bell peppers, green bell peppers, and other peppers. The subsequent case-control study included all food items that were reported as having been consumed by more than 50% of case subjects in these interviews, in addition to avocado and guacamole. For this study, case subjects had an illness that met the case definition and a reported onset of diarrhea on or after May 1. Control subjects without diarrhea were matched with case subjects according to age group and neighborhood. (For details, see the Supplementary Appendix, available with the full text of this article at NEJM.org.)

Study 2

In June 2008, because of the growing scope of the outbreak and the concern that other food vehicles might be involved, the CDC and state and local health departments in 29 states conducted a multistate case-control study to further investigate possible sources. Data were collected on patterns of eating at Mexican-style restaurants and consumption of produce, including freshly made salsa, raw jalapeño and other hot peppers, raw cilantro, raw tomatoes, and 17 other items. Case subjects had an illness that met the case definition and reported an onset of diarrhea on or after June 1. Control subjects without diarrhea were matched with case subjects according to age group and neighborhood.

Study 3

In July 2008, the departments of health in New Mexico and Arizona, the Navajo Nation, the Indian Health Service, and the CDC conducted a household-based case-control study to collect information through personal interviews about possible sources of infection and preparation of food. Data were collected about how cilantro, jalapeño peppers, serrano peppers, and tomatoes were brought into, stored, prepared, and consumed in the home. A case household was defined as one with a case subject who had an illness that met the case definition and reported an onset of diarrhea on or after June 1. Case subjects

residing in the household and the household's primary food preparer were interviewed. Control households were those without a member who was ill with diarrhea, matched with case households according to neighborhood.

Texas Case Survey

In mid-July 2008, epidemiologists at the Texas Department of State Health Services interviewed 75 case subjects who had had an onset of illness between May 1 and June 7, because these subjects had not been specifically questioned about the consumption of hot peppers early in the outbreak. The questionnaire asked about consumption of raw jalapeño and serrano peppers, raw tomatoes, and other food items.

INVESTIGATION OF CLUSTERS LINKED TO RESTAURANTS OR EVENTS

A restaurant or event cluster was defined as a single location or event in which at least two persons with the outbreak strain became ill within 7 days after their meal date and had meal dates within 10 days of one another. To identify ingredients and sources for implicated food items in clusters, nine epidemiologic studies were conducted. For all studies, a case subject was defined as a person with diarrhea who had eaten at the implicated restaurant in the week before the onset of illness. Confirmed cases were defined as cases with culture confirmation of the outbreak strain or a salmonella strain for which the PFGE pattern was not determined. Some studies also included probable cases, which were defined as cases without culture confirmation of salmonella infection. Control subjects were defined as meal companions or restaurant patrons identified by means of credit-card receipts who had eaten at the restaurant during the same time window but did not have diarrhea. Structured questionnaires that were based on the restaurant menu were administered. Recipes for menu items were collected to allow for ingredient-level analyses.

ENVIRONMENTAL AND TRACEBACK INVESTIGATIONS

State and local health and agricultural departments, the Food and Drug Administration (FDA), and the CDC conducted traceback investigations of the distribution pathway for implicated food items associated with several ill persons and restaurant clusters. Environmental assessments were conducted as part of the restaurant-cluster inves-

tigations to determine whether food handlers were ill before the onset of illness in patrons and to identify practices in food preparation, handling, and storage. The FDA collected food samples and conducted environmental investigations along the distribution chain, including at distribution centers, packing facilities, and farms, to determine possible sources of contamination.

STATISTICAL ANALYSIS

Data were entered into a database, and statistical analyses were conducted with the use of SAS software, version 9.1 (SAS Institute). Odds ratios and 95% confidence intervals were calculated, and logistic-regression analyses were conducted. Among the many sub-studies, these regression analyses were variously done with data treated as both unmatched and matched, with and without adjustment for variables, with and without imputed values for missing data, and with and without recoding for response sensitivity. Information was continually reevaluated for evidence of a common causal pathway or pathways, and the process of statistical analysis was exploratory in character.

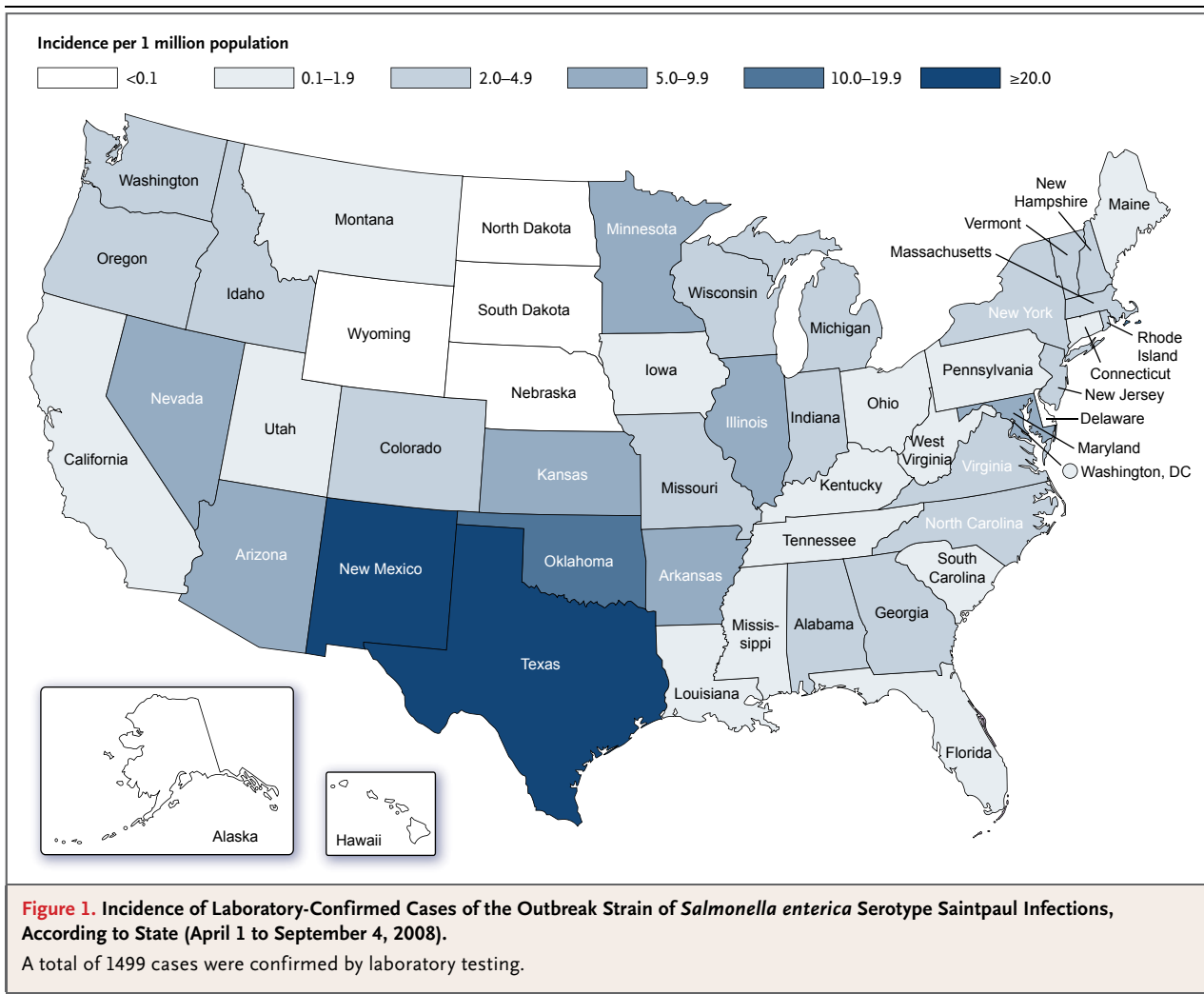
RESULTS

DESCRIPTION OF THE OUTBREAK

We identified 1500 case subjects who were infected with the outbreak strain of the salmonella Saintpaul serotype in 43 states, the District of Columbia, and Canada. The states with the highest incidence rates were New Mexico (58.4 cases per 1 million population) and Texas (24.5 per 1 million population) (Fig. 1). Illnesses began between April 16 and August 26 and peaked between mid-May and mid-June (Fig. 2). Of the case subjects, 21% were hospitalized, and infection may have contributed to two deaths (Table 1).

INVESTIGATION OF CASES NOT LINKED TO RESTAURANT CLUSTERS

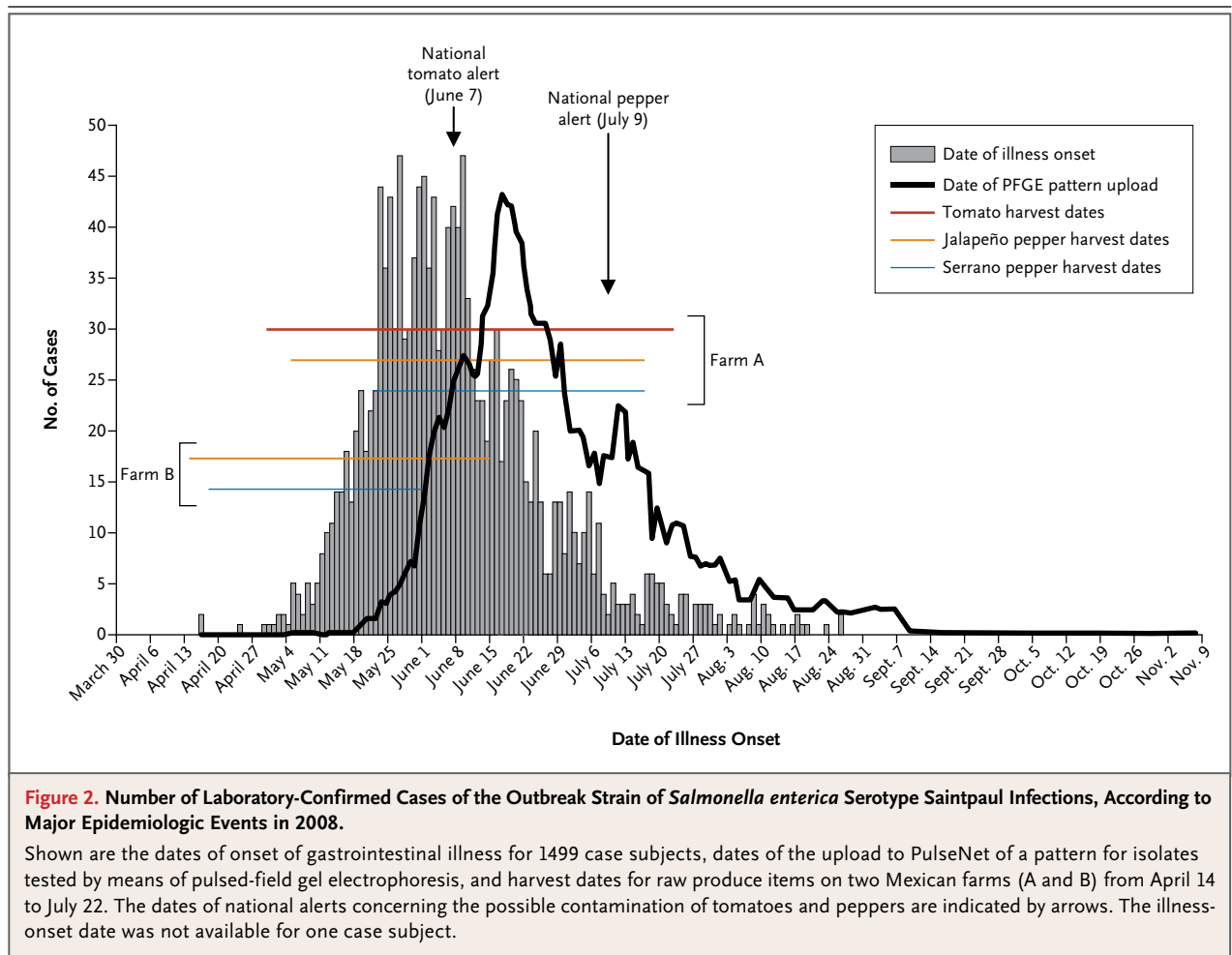
Of the 19 case subjects who were interviewed with the hypothesis-generating questionnaire, more than 50% reported consuming raw tomatoes, eggs, ice cream, potatoes, milk, tortillas, cold breakfast cereal, raw onions, salsa, ground beef, chicken, and lettuce. The food most commonly identified was raw tomatoes, reported by 16 subjects (84%); 5 (26%) reported eating "other peppers" (i.e. other than red or green bell peppers).



Study 1 included 51 case subjects and 106 matched control subjects (Table 2). On univariate analysis, illness was significantly associated with eating raw tomatoes (reported by 88% of case subjects vs. 64% of control subjects; matched odds ratio, 6.7; 95% confidence interval [CI], 1.9 to 36.0) and with eating tortillas (matched odds ratio, 2.8; 95% CI, 1.0 to 10.0). After adjustment for the consumption of tortillas, illness remained significantly associated with eating raw tomatoes (matched odds ratio, 5.6; 95% CI, 1.6 to 30.3). Illness was not significantly associated with eating salsa (matched odds ratio, 1.7; 95% CI, 0.8 to 3.8), guacamole (matched odds ratio, 1.6; 95% CI, 0.7 to 3.5), or any other food item. The consumption of hot peppers was not assessed because only 26% of case subjects reported eating other peppers in hypothesis-generating interviews.

Study 2 included 141 case subjects and 281 matched control subjects. After adjustment for sex, Hispanic ethnic background, and age, illness was significantly associated with eating at Mexican-style restaurants (matched odds ratio, 4.6; 95% CI, 2.1 to ∞) and with eating pico de gallo (a type of salsa typically composed of tomatoes, onions, hot peppers, and other ingredients) (matched odds ratio, 4.0; 95% CI, 1.5 to 17.8), corn tortillas (matched odds ratio, 2.3; 95% CI, 1.2 to 5.0), and freshly prepared salsa (matched odds ratio, 2.1; 95% CI, 1.1 to 3.9) (Table 2). Illness was not independently associated with the consumption of tomatoes, jalapeño peppers, cilantro, avocados, fresh or bottled salsa, or onions, all of which were significantly associated on univariate analysis.

Study 3 included 41 households with case



subjects and 107 households with matched control subjects. On univariate analysis, illness was significantly associated with having a raw jalapeño pepper in the home (matched odds ratio, 2.9; 95% CI, 1.2 to 7.6), and illness had a borderline association with having a raw serrano pepper in the home (matched odds ratio, 3.0; 95% CI, 0.9 to 9.6) (Table 2). Illness was not significantly associated with the presence of tomatoes, cilantro, or other food items in the home or with reported consumption of raw jalapeño peppers, raw serrano peppers, raw tomatoes, or other food items.

In the Texas survey of 75 case subjects whose illnesses began on or before June 7, 64 (85%) reported consuming raw tomatoes, 29 (39%) jalapeño peppers, 6 (8%) serrano peppers, 39 (52%) fresh salsa, 26 (35%) pico de gallo, and 27 (36%) guacamole.

INVESTIGATION OF CLUSTERS LINKED TO RESTAURANTS OR EVENTS

State and local health departments in 14 states and the District of Columbia reported 37 clusters of illness associated with either restaurants or events (Fig. 3 in the Supplementary Appendix). Of the 37 clusters, 35 were associated with restaurants, 1 with a mobile Mexican-style food vendor, and 1 with a privately catered event. Of the 35 restaurant-associated clusters, 30 (86%) involved Mexican-style restaurants. The median number of laboratory-confirmed cases for all 37 clusters was 4 (range, 2 to 47); 27 (73%) had 8 or fewer laboratory-confirmed cases.

Analytical studies of nine clusters were conducted, including eight involving Mexican-style restaurants (Table 3). A food item was implicated in six clusters. The items that had a significant association with illness were salsa (in

Table 1. Characteristics of Case Subjects with Confirmed *Salmonella enterica* Serotype Saintpaul Infections in 2008.*

Characteristic	Value
Case subjects interviewed for one or more epidemiologic studies — no./total no. (%)†	704/1500 (47)
Age — yr	
Median	31
Range	<1 to 99
Female sex — no./total no. (%)	733/1478 (50)
Hospitalization — no./total no. (%)	308/1500 (21)
Race or ethnic group — no./total no. (%)‡	
White	680/889 (76)
Hispanic	263/938 (28)
Black	25/889 (3)
American Indian or Alaskan Native	106/889 (12)
Asian or Pacific Islander	17/889 (2)
Other	61/889 (7)

* A confirmed case was defined as a laboratory-confirmed infection with *Salmonella* Saintpaul with the XbaI pattern JN6X01.0048 on pulsed-field gel electrophoresis during the period from April 1 to September 4.

† The median time from illness onset until ill persons were reached for an interview was 21 days; 90% were interviewed within 34 days.

‡ Race or ethnic group was self-reported. The number of patients who responded to the question about ethnic group was higher than the number who responded to the question about race.

three clusters), guacamole (in two clusters), and a raw jalapeño pepper garnish (in one cluster). In all three clusters in which a single ingredient was significantly implicated, the ingredient was jalapeño peppers; hot peppers were an ingredient in an implicated item in three additional clusters (jalapeño peppers in one cluster and serrano peppers in two clusters). Raw tomatoes were an ingredient in an item associated with illness in three clusters, including one in which red, round tomatoes were specifically implicated.

ENVIRONMENTAL AND TRACEBACK INVESTIGATIONS

Environmental assessments conducted as part of the epidemiologic investigations of nine restaurant clusters did not identify recent diarrheal illness among food handlers. A total of 12 tracebacks of raw Roma and red, round tomatoes were completed: 8 tracebacks from 7 sporadic cases and 4 tracebacks from restaurant clusters. These tracebacks did not converge on any one geographic location, grower, or supplier. All tomato tracebacks included sources from Mexico, Florida, or

both. Environmental investigations were conducted at five farms or packing firms in Mexico and three in Florida. Only one firm was packing tomatoes in Mexico at the time of the investigation, and all farms in Mexico and Florida had finished harvesting. The FDA analyses of approximately 183 domestic and imported tomato samples and 113 environmental swabs from tomato operations in Florida and Mexico did not identify salmonella.

Tracebacks to farms from 13 restaurant clusters were completed for jalapeño peppers from five states, including 3 restaurants (cluster D, consisting of two restaurant locations, and cluster G) in which jalapeño peppers were implicated. All 13 tracebacks led to distributors in Texas and Mexico that received jalapeño peppers from Mexico. The outbreak strain was isolated from a jalapeño pepper sample obtained from a produce importer in Texas that received jalapeño peppers from a packing facility in Nuevo Leon, Mexico. The traceback from the packing facility was complex, with commingling of products and a network of interrelated distribution points.

The FDA investigated two farms in Mexico (Farm A and Farm B) that supplied peppers to the packing facility (Fig. 2). Traceback records identified other farms that also supplied the facility during this period. Farm A, which grew Roma tomatoes in addition to jalapeño and serrano peppers, harvested all three crops between late April and late July and was an indirect supplier to the packing facility. Farm B supplied the same packing facility both through direct shipments and also indirectly through distributors. Farm B, located approximately 100 miles from Farm A, was this packing facility's main pepper supplier. Agricultural water samples from Farm A yielded salmonella but not the outbreak strain. The FDA did not collect tomatoes at Farm A. The outbreak strain was isolated from two environmental samples, agricultural water, and serrano peppers on Farm B, which grew jalapeño peppers and serrano peppers, but not tomatoes, and harvested produce from mid-April to mid-June. The Colorado Department of Public Health and Environment isolated the outbreak strain from a jalapeño pepper collected from the home of a case subject in Colorado and traced this pepper from the grocery store where it had been purchased to another distributor in Texas. The source of these jalapeño peppers was not determined.

Table 2. Odds Ratios for Selected Food and Other Exposures in Three Case–Control Studies of *Salmonella enterica* Serotype Saintpaul Infections Not Linked to Restaurant Clusters in 2008.*

Study and Exposure	Case Subjects Exposed	Control Subjects Exposed	Odds Ratio (95% CI)
	no./total no. (%)		
Study 1			
Raw tomato			
With adjustment†	42/48 (88)	67/104 (64)	5.6 (1.6–30.3)
Without adjustment	42/48 (88)	67/104 (64)	6.7 (1.9–36.0)
Tortilla	39/47 (83)	69/104 (66)	2.8 (1.0–10.0)
Salsa‡	27/48 (56)	47/104 (45)	1.7 (0.8–3.8)
Guacamole‡	16/50 (32)	26/103 (25)	1.6 (0.7–3.5)
Study 2§			
Eating at Mexican-style restaurant	68/138 (49)	64/278 (23)	4.6 (2.1–∞)
Pico de gallo	35/127 (28)	26/257 (10)	4.0 (1.5–17.8)
Corn tortilla	51/126 (40)	67/251 (27)	2.3 (1.2–5.0)
Salsa	60/130 (46)	73/245 (30)	2.1 (1.1–3.9)
Study 3			
Jalapeño pepper			
In home	26/41 (63)	42/107 (39)	2.9 (1.2–7.6)
Consumed, with adjustment for sex and age‡	19/41 (46)	35/107 (33)	1.7 (0.6–5.0)
Serrano pepper			
In home‡	9/41 (22)	9/107 (8)	3.0 (0.9–9.6)
Consumed, with adjustment for sex and age‡	4/41 (10)	7/107 (7)	0.5 (0.1–3.1)
Raw tomato in home‡	19/41 (46)	38/107 (36)	1.6 (0.6–4.9)

* Study 1, the first multistate study, was conducted from May 26 to June 4 in Arizona, New Mexico, the Navajo Nation, and Texas. Study 2, the second multistate study, was conducted from June 26 to July 3 in 29 states: Arizona, California, Colorado, Connecticut, Georgia, Illinois, Indiana, Kansas, Kentucky, Maine, Maryland, Massachusetts, Michigan, Missouri, Nevada, New Mexico, New York, North Carolina, Ohio, Oklahoma, Oregon, Pennsylvania, Tennessee, Texas, Vermont, Virginia, Washington, West Virginia, and Wisconsin. Study 3, a household-based study, was conducted from July 11 to July 25 in Arizona, New Mexico, and the Navajo Nation.

† This analysis was adjusted for the consumption of tortillas in the week before the onset of illness.

‡ The consumption of this item was not significantly associated with illness.

§ The analyses listed for study 2 were adjusted for sex, Hispanic ethnic group, and age.

CONTROL MEASURES

Multiple public advisories were issued recommending that consumers avoid eating implicated produce items. These included an advisory on June 3, limited to New Mexico and Texas, recommending that consumers avoid eating certain types of tomatoes; this advisory was issued nationwide on June 7. A nationwide advisory concerning jalapeño peppers on July 9 was followed by a warning on July 30 not to eat peppers grown or packed in Mexico (Fig. 4 in the Supplementary Appendix).

DISCUSSION

This outbreak of foodborne disease in the United States was one of the largest salmonella outbreaks ever identified. Because many salmonella illnesses are not confirmed by culture, it is likely that many more occurred than were identified.⁷

The results of multiple investigations indicate that jalapeño peppers were the major vehicle for transmission, and serrano peppers were also a vehicle. These findings include epidemiologic associations between illness and consumption of

Table 3. Analysis of Nine Restaurant-Associated Clusters of *Salmonella enterica* Serotype Saintpaul Infections in Arkansas, Minnesota, Missouri, North Carolina, New York, and Texas in 2008.*

Cluster Identifier	Cluster Location	Date Range of Meals Consumed	Implicated Food and Its Ingredients	Implicated Food in Ingredient-Level Analysis	Case Subjects Exposed no./total no. (%)	Control Subjects Exposed no./total no. (%)	Odds Ratio (95% CI)
A	East Texas	May 4 to June 4	None	None	0/14	0/45	NA
B	New York City	May 22 to June 5	None	None	0/8	0/55	NA
C	Central Texas	May 23 to June 9	Red salsa (fresh and canned tomatoes, serrano peppers, cilantro, green onion, salsa spices)†	None	19/20 (95)	24/34 (71)	30.0 (1.6 to 1311.0)‡
D	North Texas	May 23 to June 12	Salsa (canned tomatoes, jalapeño peppers, dried garlic powder, red pepper flakes, salt)	Jalapeño pepper	21/21 (100)	25/31 (81)	12.8 (1.3 to ∞)§¶
E	Wichita Falls, TX	May 30 to June 2	Salsa (large tomatoes, jalapeño peppers, dried garlic powder, red pepper flakes, salt)	Jalapeño pepper	45/47 (96)	16/40 (40)	24.7 (3.4 to ∞)‡§
F	Charlotte, NC	June 8 to June 14	Guacamole (Roma tomatoes, serrano peppers, red onions, cilantro, avocados, lime juice, salt)	ND	4/4 (100)	42/113 (37)	8.7 (1.1 to ∞)‡
G	Roseville, MN	June 13 to June 22	Garnish (jalapeño peppers, red bell peppers)	Jalapeño pepper	17/19 (89)	8/73 (11)	62.0 (12.0 to 321.0)‡
H	Little Rock, AR	June 14 to June 22	None	None	0/7	0/21	NA
I	Jefferson County, MO	June 28 to July 2	Guacamole (red round tomatoes, jalapeño peppers, avocados, onions, lettuce, lime juice, cilantro)	None	5/6 (83)	13/44 (30)	11.3 (1.1 to 581.5)¶
			Red, round tomatoes	None	6/6 (100)	22/44 (50)	7.6 (1.0 to >999.0)¶

* NA denotes not applicable, and ND not done.

† Red salsa was eaten as an appetizer with chips or with other food items.

‡ This odds ratio was calculated by means of multivariable analysis.

§ This matched analysis was adjusted for sex, meal date, and age group (<10 years vs. ≥10 years).

¶ This odds ratio was calculated by means of univariate analysis.

hot peppers, the convergence of tracebacks to a single farm that grew both types of peppers but not tomatoes, and isolation of the outbreak strain from agricultural water and serrano peppers collected on that farm. The consumption of jalapeño peppers was not specifically implicated in either study in which this hypothesis was explicitly tested (studies 2 and 3). However, study 2 implicated foods typically made or consumed with hot peppers, and study 3 implicated the presence of jalapeño peppers in the home. One explanation for the results of study 2 could be that produce items are consumed in small quantities as ingredients of other dishes and might not be recognized or always remembered after several weeks, making the implication of such items more difficult.⁸ In study 3, the respondent was often the food preparer, who would be likely to know the ingredients.

Early in the outbreak, raw tomatoes were thought to be a vehicle because study 1, conducted by standard methods, yielded a strong association between illness and consumption of raw tomatoes. Tomatoes have been implicated in many salmonella outbreaks.⁹⁻¹¹ The initial finding that tomatoes were a source was supported by the observation that the number of new cases decreased shortly after the national tomato alert. The Texas survey, in which case subjects from early in the outbreak were specifically asked about the consumption of hot peppers and tomatoes, showed a high frequency of tomato consumption, which was similar to the frequency found in study 1, whereas fewer than half of those surveyed reported eating hot peppers. However, tomato tracebacks did not converge on any one geographic location, supplier, or growing area, and the FDA analyses of tomato samples did not identify salmonella.

The observed epidemiologic association with tomatoes may reflect collinearity between tomatoes and hot peppers, meaning that an association was identified because tomatoes were often eaten with hot peppers. It could also reflect amplified growth of salmonella in food items, such as salsa, containing both tomatoes and contaminated hot peppers. The decline in cases shortly after the nationwide tomato advisory could be explained if avoidance of raw tomatoes indirectly reduced exposure to contaminated hot peppers. The low frequency of reported hot-pepper con-

sumption in the Texas survey could be due to unrecognized exposure to hot peppers as ingredients in other foods.

Salsa and guacamole, both foods typically containing tomatoes and hot peppers, were implicated repeatedly in cluster investigations; these foods may have provided a medium for salmonella growth. Cut or diced tomatoes require prompt refrigeration because of the potential for salmonella growth.¹² However, salsa and guacamole are kept at room temperature for hours in some commercial settings.¹³ The addition of both fresh garlic and lime juice to salsas can suppress the growth of salmonella.¹⁴

On the basis of FDA investigations, pepper contamination probably occurred on the farm. This may not be unusual; a small survey of Mexican farms that grow chile peppers indicated that 6 of 14 irrigation-water samples (43%) and 3 of 5 pepper rinses (60%) yielded salmonella (none of the serotypes were Saintpaul).¹⁵ From 1972 through 1999, only 1.2% of human salmonella isolates that were serotyped at public and private laboratories in Mexico were serotype Saintpaul.¹⁶

This outbreak investigation highlights the recurring challenges of epidemiologic identification of ingredients in foods that are commonly consumed, rapid identification and investigation of local clusters, the need to continue exploring hypotheses during an ongoing outbreak, and produce tracing in the supply chain. Traceback issues such as commingling, repacking, varying degrees of product documentation throughout the supply chain, difficulty in linking incoming with outgoing shipments to the next level in the distribution chain, and the complexity of the distribution chain continue to hinder product-tracing efforts. Improvements in product-tracing systems and the ability of the systems to work together are needed for more rapid tracing of implicated products through the supply chain in order to maximize public health protection and minimize the economic burden to industry. In addition, an understanding of the mechanisms and ecologies that can lead to contamination of produce on farms and the institution of additional control measures from the source throughout the supply chain are critical for preventing similar outbreaks in the future.

Disclosure forms provided by the authors are available with the full text of this article at NEJM.org.

REFERENCES

1. Preliminary FoodNet data on the incidence of infection with pathogens transmitted commonly through food — 10 states, 2009. *MMWR Morb Mortal Wkly Rep* 2010;59:418-22.
2. Sivapalasingam S, Friedman CR, Cohen L, Tauxe RV. Fresh produce: a growing cause of outbreaks of foodborne illness in the United States, 1973 through 1997. *J Food Prot* 2004;67:2342-53.
3. Lynch ME, Tauxe RV, Hedberg CW. The growing burden of foodborne outbreaks due to contaminated fresh produce: risks and opportunities. *Epidemiol Infect* 2009;137:307-15.
4. *Salmonella* surveillance: annual summary, 2006. Atlanta: Centers for Disease Control and Prevention, 2008. (<http://www.cdc.gov/ncidod/dbmd/phlisdata/salmtab/2006/SalmonellaAnnualSummary2006.pdf>)
5. Antigenic formulae of the *Salmonella* serovars. 9th ed. Paris: WHO Collaborating Centre for Reference and Research on *Salmonella*, 2007. (<http://www.scacm.org/divc/Antigenic%20Formulae%20of%20the%20Salmonella%20Serovars%202007%209th%20edition.pdf>)
6. Ribot EM, Fair MA, Gautom R, et al. Standardization of pulsed-field gel electrophoresis protocols for the subtyping of *Escherichia coli* O157:H7, *Salmonella*, and *Shigella* for PulseNet. *Foodborne Pathog Dis* 2006;3:59-67.
7. Voetsch AC, Van Gilder TJ, Angulo FJ, et al. FoodNet estimate of the burden of illness caused by nontyphoidal *Salmonella* infections in the United States. *Clin Infect Dis* 2004;38:Suppl 3:S127-S134.
8. Mahon BE, Pönkä A, Hall WN, et al. An international outbreak of *Salmonella* infections caused by alfalfa sprouts grown from contaminated seeds. *J Infect Dis* 1997;175:876-82.
9. Hedberg CW, Angulo FJ, White KE, et al. Outbreaks of salmonellosis associated with eating uncooked tomatoes: implications for public health. *Epidemiol Infect* 1999;122:385-93.
10. Gupta SK, Nalluswami K, Snider C, et al. Outbreak of *Salmonella* Braenderup infections associated with Roma tomatoes, northeastern United States, 2004: a useful method for subtyping exposures in field investigations. *Epidemiol Infect* 2007;135:1165-73.
11. Greene SK, Daly ER, Talbot EA, et al. Recurrent multistate outbreak of *Salmonella* Newport associated with tomatoes from contaminated fields, 2005. *Epidemiol Infect* 2008;136:157-65.
12. Conference for Food Protection. Council III issues: results — III-005: cut tomatoes as PHF (TCS Food). Lincoln, CA: Conference for Food Protection, 2006. (<http://www.foodprotect.org/media/meeting/2006Final-Issues.pdf>)
13. Kirkland E, Green LR, Stone C, et al. Tomato handling practices in restaurants. *J Food Prot* 2009;72:1692-8.
14. Ma L, Zhang G, Gerner-Smidt P, Tauxe R, Doyle M. Survival and growth of *Salmonella* in salsa and related ingredients. *J Food Prot* 2010;73:434-44.
15. Gallegos-Robles MA, Morales-Loredo A, Alvarez-Ojeda G, et al. Identification of *Salmonella* serotypes isolated from cantaloupe and chile pepper production systems in Mexico by PCR-restriction fragment length polymorphism. *J Food Prot* 2008;71:2217-22.
16. Gutiérrez-Cogco L, Montiel-Vázquez E, Aguilera-Pérez P, González-Andrade MC. *Salmonella* serotypes identified in Mexican health services. *Salud Publica Mex* 2000;42:490-5. (In Spanish.)

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